Section 4
L1B Version Status

Status and Summary of First Year of Terra Production Code Operations

Objectives and Key Results

- Objectives:
  - *Convey the scope of changes in the Level 1B code and lookup-tables (LUTs) for the first year of Terra operations,*
  - *Describe the impact of those changes on the L1B product*
  - *Describe our readiness to support reprocessing*

- Key Results:
  - *9 different L1B versions have been used in Terra operations with some significant improvements made and problems solved*
    - *Several of the problems have been identified by Science Team members with whom we have had excellent interactions*
  - *Fixes to L1B problems were rapidly implemented into operations, with excellent support from SDST and the GDAAC*
    - *Typically 1 day for a LUT update, 2 weeks for a code change*
  - *The L1B code architecture fully supports hands-off reprocessing, but appropriate science updates to the LUTs are needed prior to commencing reprocessing.*

Outline/Reference

- Outline:
  - Describe versions used in GDAAC operations
  - Summarize of major effects on products
  - Describe time-dependent look-up tables (LUTs)
- Reference -- Level 1B information on MCSTWEB (http://mcstweb.gsfc.nasa.gov/product.html):
  - Code change history
  - LUTs change history
  - File specifications and change histories
  - Reference documents (Word 98):
    - LUTs description
    - Product User's Guide and Data Dictionary
    - High-Level Code design
  - Product Caveats (old -- these are currently being revised)

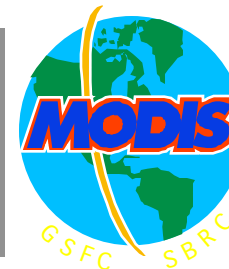# L1B Versions Used in GDAAC Operations
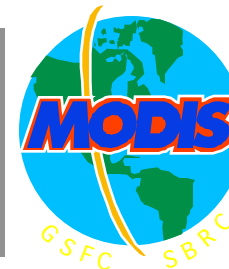
(A.B.C.D, where A.B.C = PGE Version and D = LUT update relative to that version)

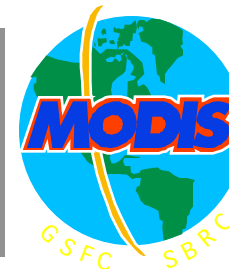| Version	Data start (approx.)	Comments
2.3.2.0	(first light)	Pre-launch calibration (SMWIR Itwk/Vdet = 79/190).
2.3.2.2 (LUT)	2000-056 16:20	LUTs derived from on-orbit data. LUTs changed: • Emissive bands calibration and uncertainty LUTs • Reflective bands calibration and uncertainty LUTs • Uncertainty index scaling factors • Detector quality flag
2.3.2.3 (LUT)	2000-077 16:00	"St. Patrick's Day Update" LUTs derived from on-orbit data. SMWIR Itwk/Vdet = 110/226. LUTs changed: • Reflective bands calibration and uncertainty LUTs
2.4.2.0 (code)	2000-162 11:55	Major code changes: • Corrected indexing bug affecting emissive bands (this appeared in the product as if something was wrong with RVS). • Corrected bug for determining when the moon is in the SVP (sign error) • Maximum number of scans raised to 208 (consistent with L1A code)

Version	Data start (approx.)	Comments
2.4.3.1 (code & LUTs)	2000-231 13:20	Major code changes: • Corrected bug in emissive bands preprocessing for PC bands X-talk. • Interpolation of scaled integers for non-functional (dead) detectors. • Time-dependent LUTs architecture. Emissive bands LUT changes: • PC bands X-talk LUTs (from day 084 moon observation) • Calibration LUTs (from day 102 BB cool-down observation) • RVS (for mirror side 2 only, from day 118 observation of NAD closed) • L_max for bands 31 and 32 increased Reflective bands LUT changes: • Calibration LUTs (from day 171 solar diffuser observation) • SWIR OOB leak correction turned OFF. Other changes: • Detector quality flag -- some detectors flagged as dead
2.4.4.0 (code)	2000-287 21:55	Major code changes: • New emissive band algorithm to compute $<DN_{SV}>$ with moon in SVP. • Corrected bug in emissive bands preprocessing for the 40 scans preceding or following a sector rotation or Ecal • Corrected indexing bug in SWIR OOB correction (switch remained OFF). • Several other bug fixes affecting metadata.

L1B Versions Used in GDAAC Operations (cont.)

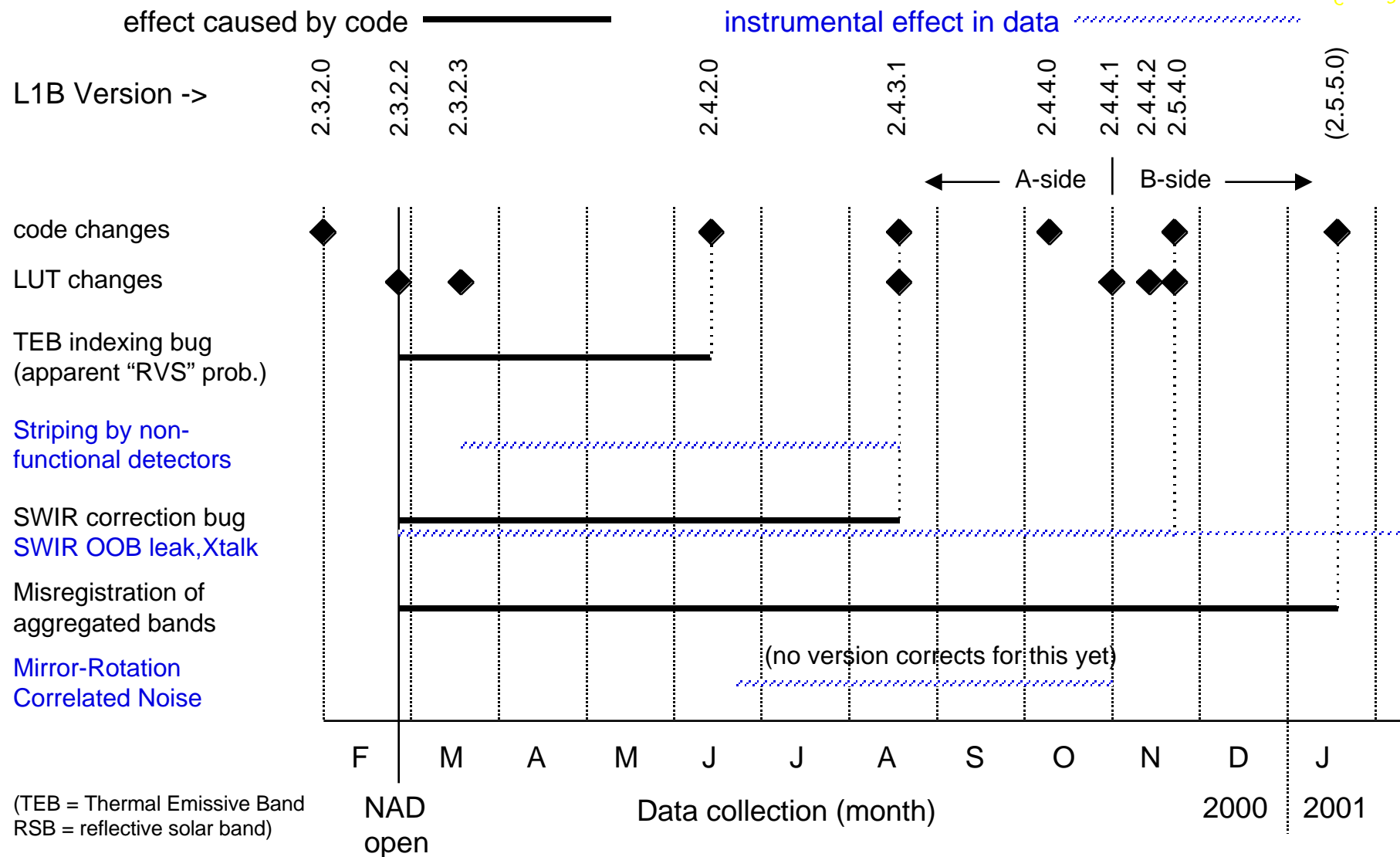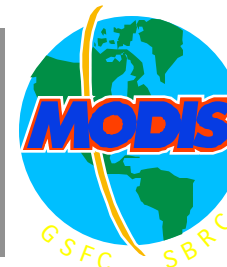| Version	Data start (approx.)	Comments	
2.4.4.1 (LUTs)	2000-304 15:55	Switch to B-side. Final values for SMWIR ltwk/Vdet = 79/110 First implementation of time-dependent LUTs (A-side/B-side) A-side calibration LUTs remained the same as before. Emissive bands LUT changes: • B-side calibration LUTs (from days 305/306 BB observations) • Some B-side uncertainty coefficient LUTs • L_max for several bands increased (both A and B side) Reflective bands LUT changes: • B-side calibration LUTs (from day 305 solar diffuser observation) • B-side uncertainty coefficient LUTs Other changes: • Detector quality flag -- all B-side detectors are functional.	
2.4.4.2 (LUTs)	2000-316 10:10	B-side only: SWIR OOB correction switch turned ON and new SWIR LUTs (aimed at improving the first subsample of 500m bands)	
2.5.4.0 (code & LUTs)	2000-328 15:55	Major changes: • Aqua compatible code and metadata • Removed obsolete metadata • New SWIR OOB algorithm & LUTs (for B-side only)	**(Currently in ops on 1/22/2001)**

Future L1B Version

Version	Status	Comments
2.5.5.0 (code)	delivered to SDST, passed SDST test, delivered to GDAAC SSI&T 1/19/2001	Code changes: • Corrected bug in aggregation algorithm. Aggregated images were not spatially registered correctly with native resolution images - 250m error in 250m_to_500m aggregated image - 500m error in 500m_to_1km aggregated image - 750m error in 250m_to_1km aggregated image • Added uncertainty SDS attributes (contain values to convert UI to %) • Added QA attribute • Added attribute for solar irradiance on reflective detectors

# Summary of Major Effects on L1B Products

effect caused by code ▬▬▬▬▬   instrumental effect in data ∿∿∿∿∿∿∿∿∿∿∿∿

L1B Version ->
2.3.2.0 2.3.2.2 2.3.2.3   2.4.2.0   2.4.3.1   2.4.4.0 2.4.4.1 2.4.4.2 2.5.4.0   (2.5.5.0)

◄── A-side │ B-side ──►

code changes

LUT changes

TEB indexing bug
(apparent "RVS" prob.)

Striping by non-
functional detectors

SWIR correction bug
SWIR OOB leak,Xtalk

Misregistration of
aggregated bands

Mirror-Rotation
Correlated Noise

(no version corrects for this yet)

F   M   A   M   J   J   A   S   O   N   D   J

(TEB = Thermal Emissive Band   NAD   Data collection (month)   2000   2001
RSB = reflective solar band)   open

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L1B Time-Dependent LUTs

- Incorporate multiple LUT values, time-tagged with data collection time, into the LUT HDF file

- L1B code determines the LUT values to use based on data collection time at the middle of the granule.

- Once determined, all scans of the granule use same values.

- Types of time dependence:
  - constant
  - series of step-functions
  - composite step function/piece-wise linear (TBD)

- Implemented in V2.4.3.1 and first used operationally in V2.4.4.1 for dynamically switching between A & B side LUTs

- *Architecture of the code fully supports hands-off reprocessing. However, science updates to the LUT values are needed prior to beginning reprocessing.*
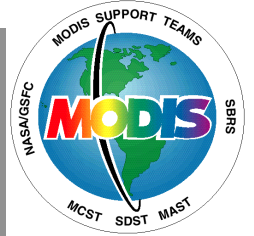
Section 5
RSB Algorithm as Implemented
Current L1B

Reflective Solar Bands Calibration

RSB L1B Calibration Algorithm Using the SD/SDSM

- Summary of pre-launch SIS calibration of MODIS detectors

- Current on-orbit calibration algorithm in L1B production

- On-orbit calibration caveats

Reflective Solar Bands Calibration

Pre-launch Calibration

- Each RSB detector was calibrated using the SBRS SIS during thermal vacuum at three instrument thermal plateaus.
- The algorithm for each plateau is

$$L = L_0 + \frac{dn*}{R*}$$

  where L is SIS radiance, L_0 is a fitting offset taken to be zero, and R^* is the detector gain. dn* is the detector response after correction for dark response (SV), RVS, and instrument temperature. In addition, the SWIR bands are corrected for a 5.1 µm thermal leak (both in SD observations and EV data). R* is determined by band, detector. sub-frame, and mirror side.
- R* at the three instrument temperature plateaus was used to determine the instrument thermal coefficients.

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Reflective Solar Bands Calibration

On-Orbit Calibration

- SD: Calibrate the response of all MODIS reflective solar bands (RSB):

  SDS Open mode - Bands 1-7, 17-19, and 26

  SDS Closed mode - All Bands (used for Bands 8-16 which saturate in SDS open mode).

- SDSM: Monitor time dependent degradation of the solar diffuser. Only SD Open mode data is currently used for analysis.

January 22, 2001

Reflective Solar Bands Calibration

MODIS RSB Production and Calibration Ranges
(for at launch programable gains)
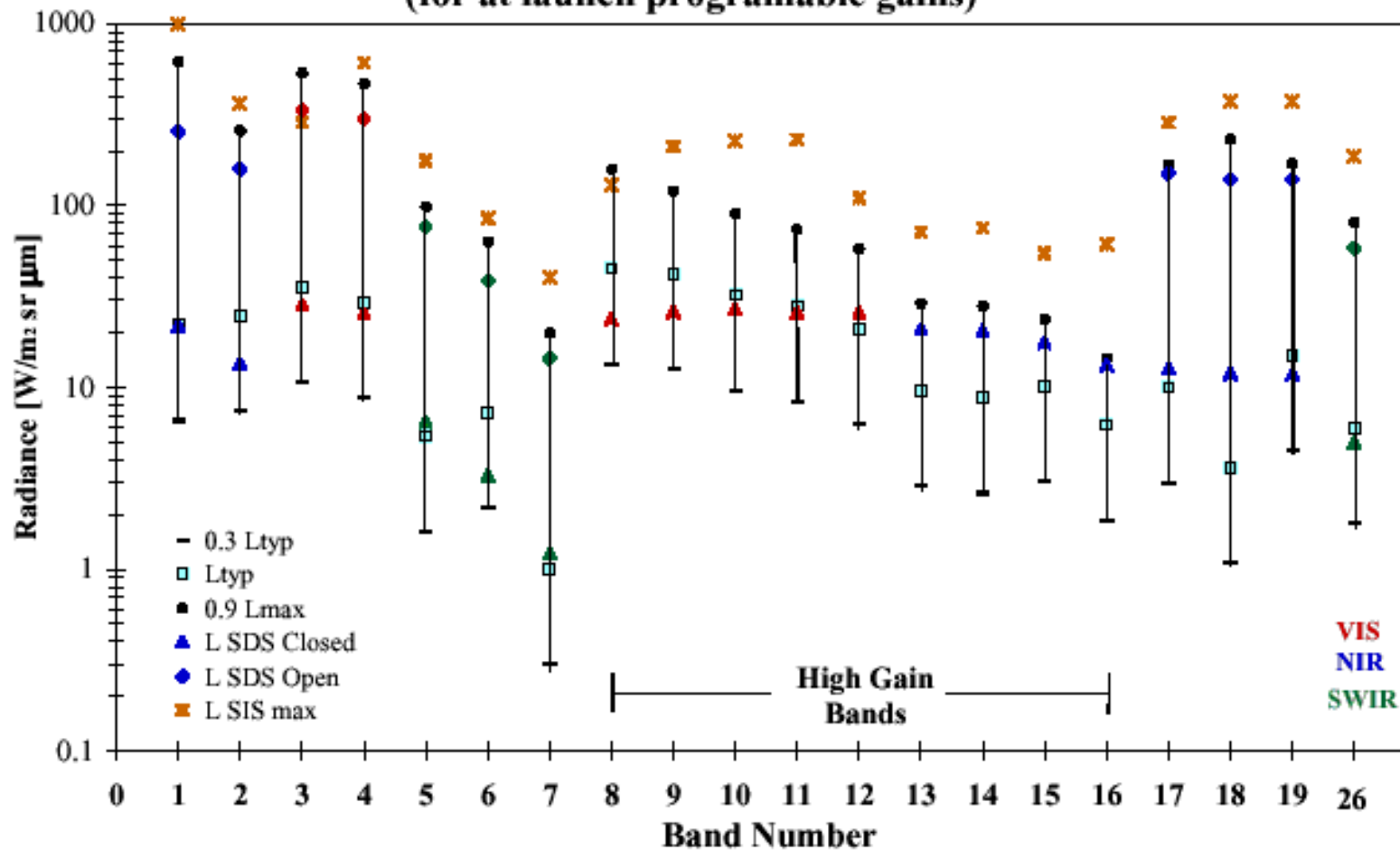
Reflective Solar Bands Calibration

On-Orbit Calibration: SD/SDSM Geometry
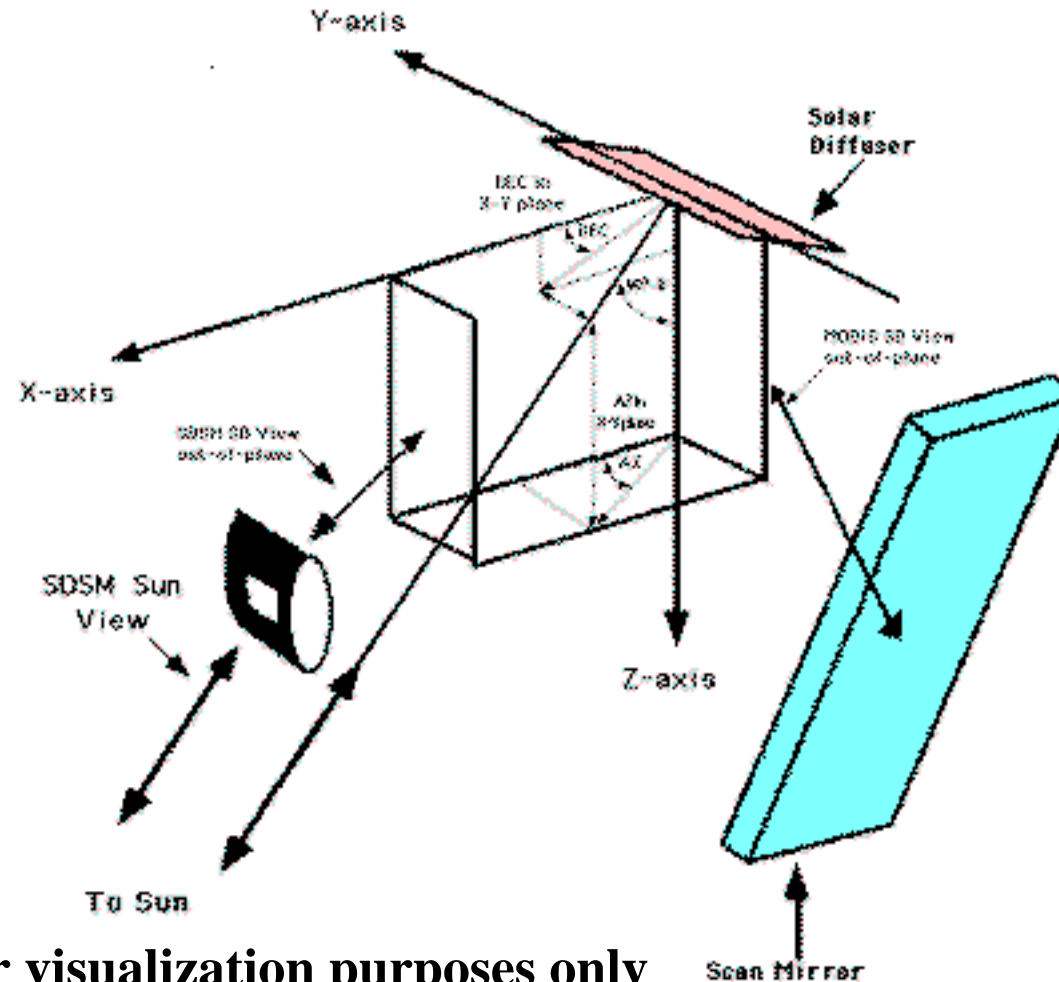
Cartoon for visualization purposes only

Reflective Solar Bands Calibration

On-Orbit Calibration

- The two basic physics equations are:

$$L = L_0 + \frac{dn^*_{EV}}{R^*}$$

$$\cos(\ ) = \frac{L}{E}$$

where L0 is taken to be zero.

- MODIS reflectance factor is:

$$_{EV}\cos(\ _{EV}) = m_1 dn^*_{EV} d^2_{Earth-Sun,EV}$$

On-Orbit Calibration

- The calibrated parameters are:

$$m_1 = \frac{plBRF(_{SD}, _{SD})\cos(_{SD})}{<dn^*_{SD}>} \ \frac{}{d^2_{Earth-Sun,SD}}$$

$$R^* = \frac{}{m_1 E_{Sun}}$$

m1 and R* are scaling coefficients between dn^*_{EV}

and the reflectance factor and radiance respectively

Reflective Solar Bands Calibration

On-Orbit Calibration

θ_{SD}, ϕ_{SD} the solar zenith and azimuth angles in the SD coordinate system

plBRF   the pre-launch calibrated SD BRF

the SD screen attenuation function determined during the MODIS Yaw Maneuvers ($\Gamma = 1$ for the SDS Open calibration mode)

the SD BRF degradation factor determined with the SDSM

$d_{\text{Earth-Sun, Sector}}$ the Earth-Sun distance at the time of the calibration or EV measurement

E_{Sun} relative spectral response weighted solar irradiance

0.4-0.8 µm Thuillier et al., 1998; 0.8-1.1 µm Neckel and Labs, 1984; Above 1.1 µm Smith and Gottlieb, 1974.

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January 22, 2001

Reflective Solar Bands Calibration

On-Orbit Calibration: Characterization Summary

- Comparison of pre-launch to on-orbit m_1 is consistent within SIS uncertainty.
- Yaw Maneuvers were completed April 25-26, 2000. SD BRF validation, SDSM SD view relative BRF determination, SD screen attenuation function, and SDSM sun view screen attenuation function analyses using yaw data completed in June, 2000. More work is needed on the screen attenuation functions.
- Current Calibration schedule is one Open and Closed mode observation per week. This will drop to one per two weeks in July, 2001.
- Transition from A side to B electronics side went smoothly with no surprises in RSB.
- Well over 100 calibrations using the SD/SDSM have been performed. The data set is large enough to properly trend various instrumental parameters. Trending analysis in the RSB is on-going.

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Reflective Solar Bands Calibration

Comparison of Pre-launch to Day 2000055 Calibrations
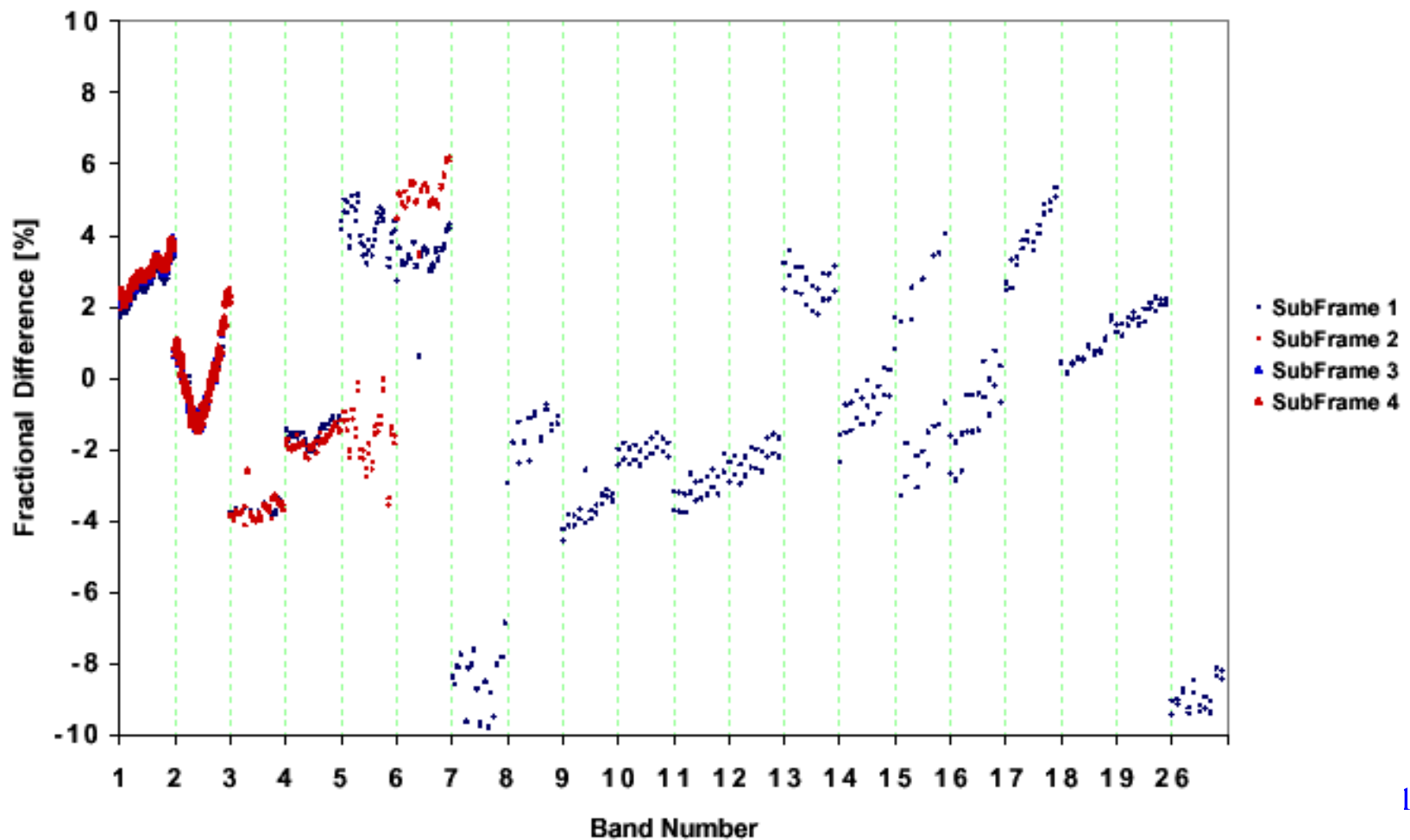
Reflective Solar Bands Calibration

On-Orbit RSB Calibration
m_1 for days 2000068, 2000171 and 2000305
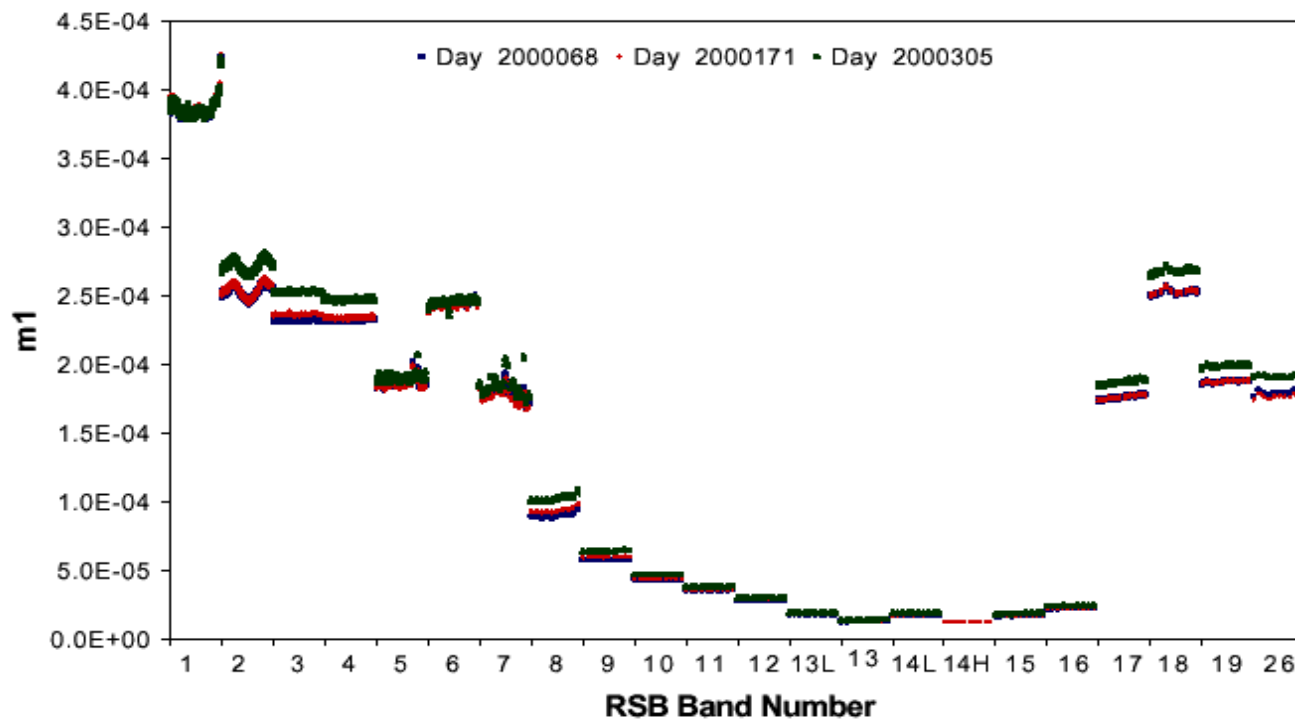
Reflective Solar Bands Calibration

On-Orbit Calibration: Caveats

- Model for correction of m_1 variation in SDS closed mode is not implemented. Work is on-going

- Band 14 high gain is saturated in both Open and Closed screen modes for the pre-launch gain setting during the day ranges: launch-70, 174-257, and after 304 (Bside change).

- The SD degradation algorithm does not currently include a model based SDSM Sun view response correction. Work on this is on-going. The SD degradation factor is not currently applied to m_1.

January 22, 2001

Reflective Solar Bands Calibration

On-Orbit RSB Calibration:Caveats

- Time dependent m_1 LUTs are not currently used in L1B. However, time dependent LUTs are now supported in L1B and time dependent m_1 LUTs will be implemented.
- The effect of non-zero L_0 on m_0, m_1 and R* has been derived from the basic physics equations. This is currently being re-examined in greater detail.

Reflective Solar Bands Calibration

m_1 variation in SDS closed mode
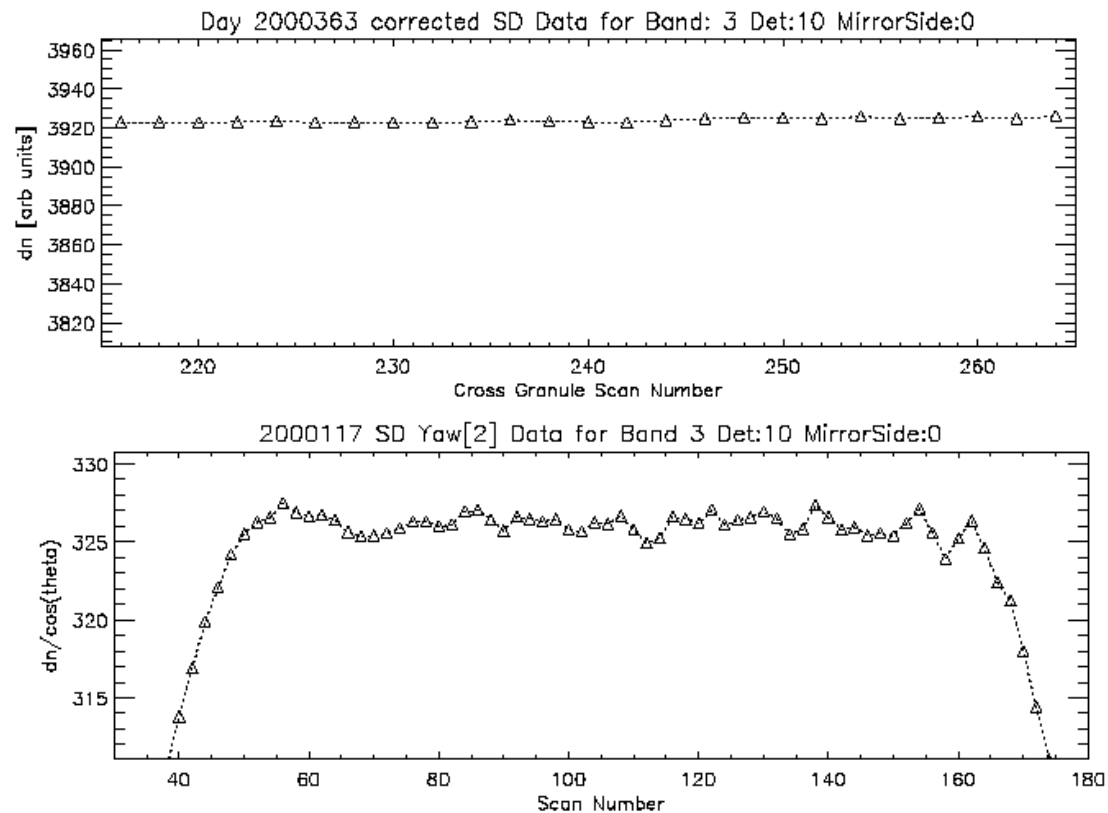
Reflective Solar Bands Calibration

m_1 determination when B14 high is saturated

- Band 14 high gain is saturated in both Open and Closed screen modes for the pre-launch gain setting during the day ranges: launch-70, 174-257, and after 304 (Bside change). The m_1 value for Band 14 high gain is inferred through analysis of the L1A EV data. A scale factor is determined for each detector and applied to the 14 low gain m_1 value to yield the 14 high gain m_1 value

$$F_{14} = \left\langle \frac{dn_{high}}{dn_{low}} \right\rangle; \quad m_1^{hi} = \frac{m_1^{lo}}{F_{14}}$$
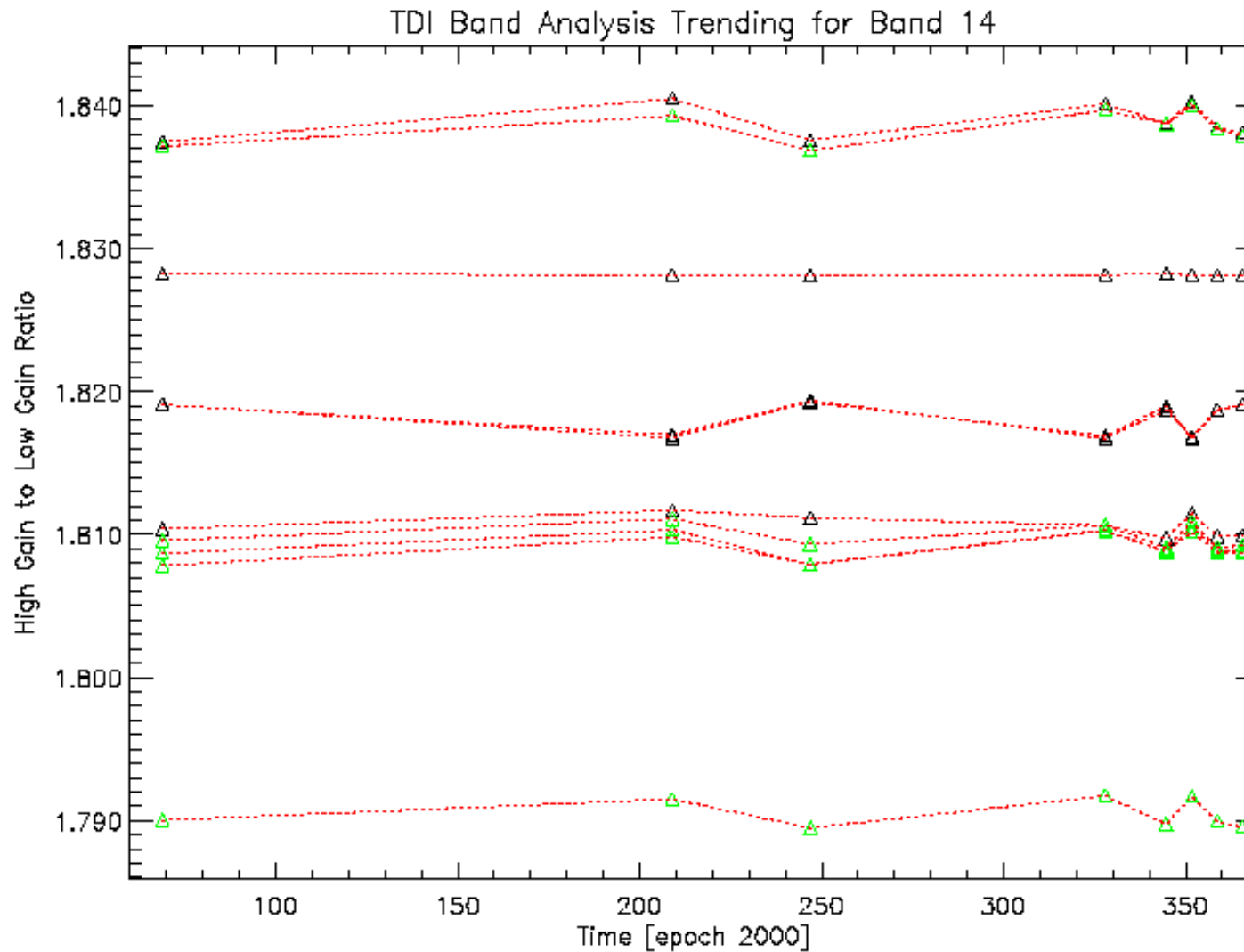
January 22, 2001

Reflective Solar Bands Calibration

TDI Band Analysis Trending for Band 14

Reflective Solar Bands Calibration

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January 22, 2001
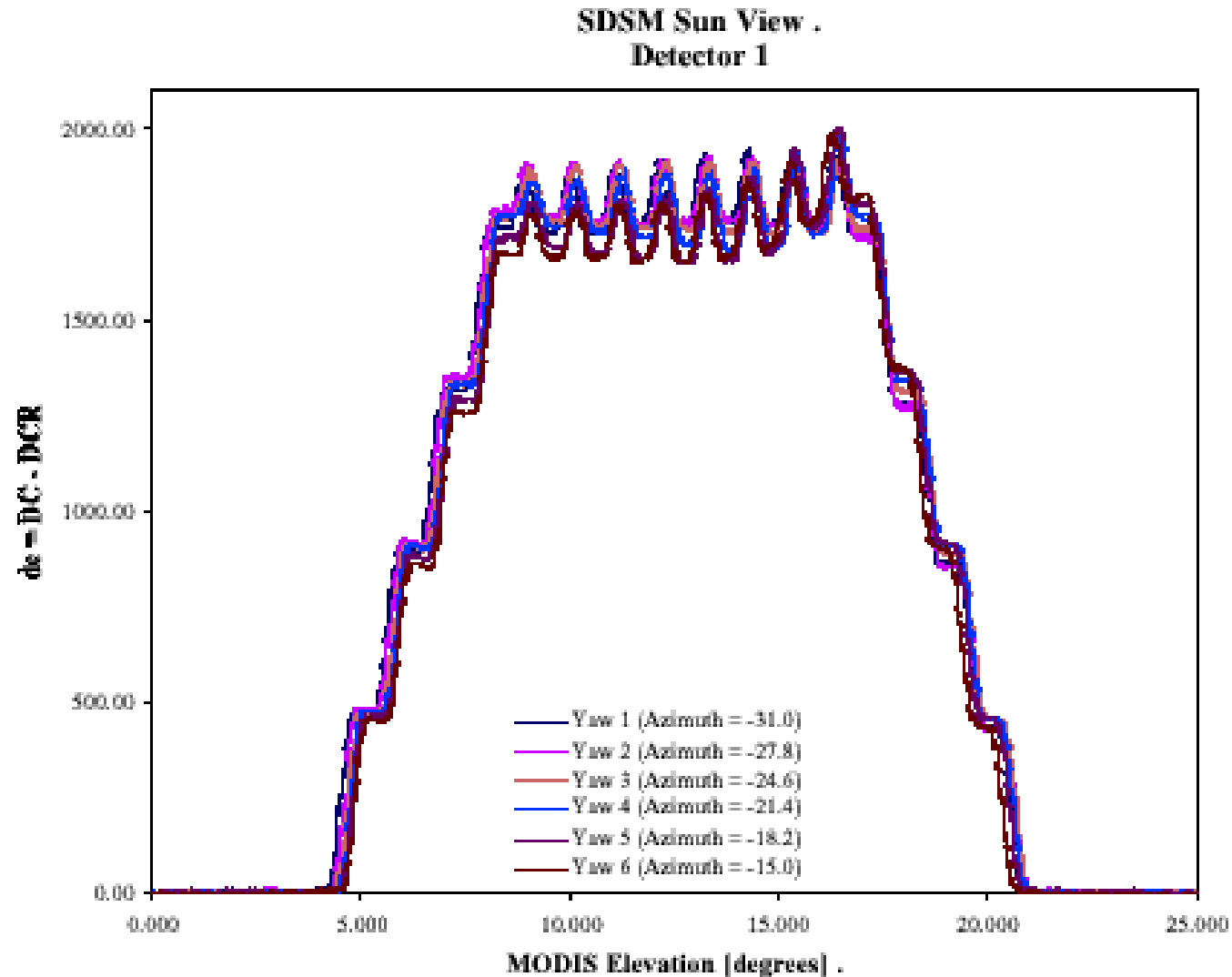
Reflective Solar Bands Calibration

On-Orbit RSB Calibration
m_1 for days 2000068, 2000171 and 2000305
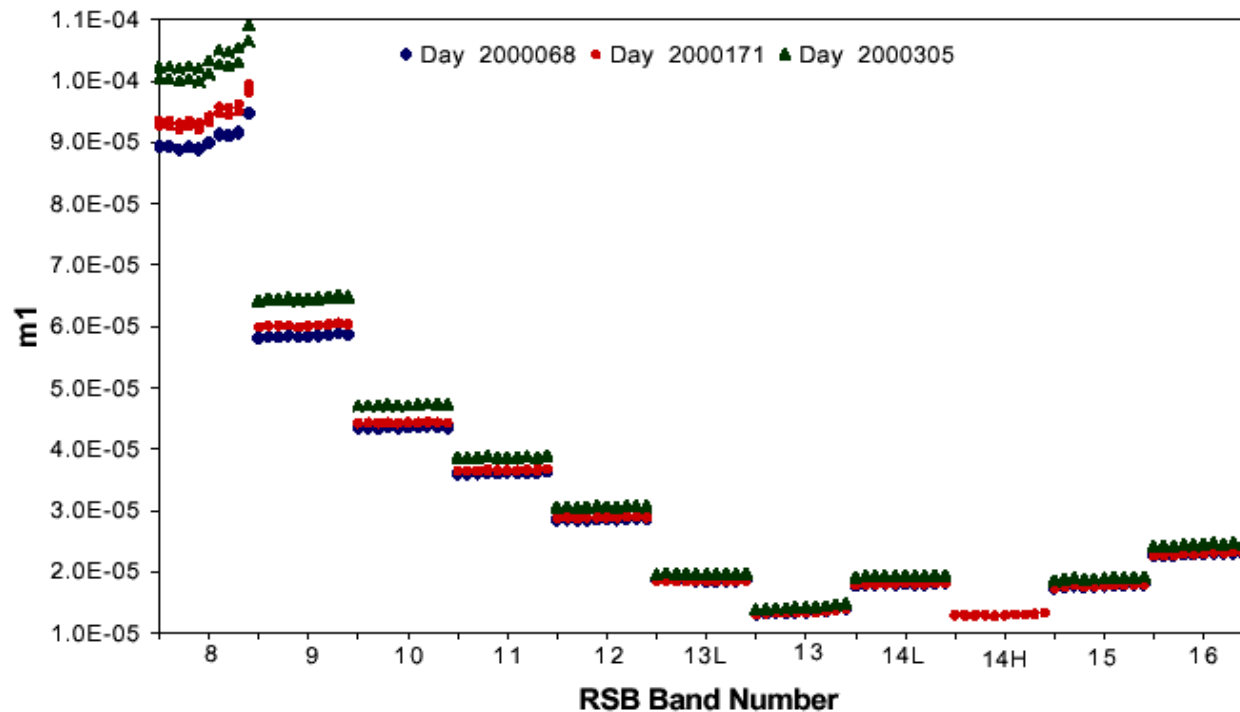
Section 6

TEB Algorithm as Implemented in the Current L1B

Thermal Emissive Bands
Radiometric Calibration Algorithm

Objective
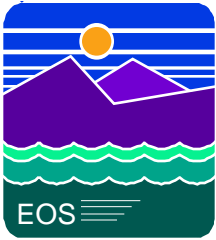
- Pre-launch calibration algorithm overview
    - TV testing and calibration fitting method
    - OBC BB emissivity
    - RVS
- Changes made after launch
    - On-orbit algorithm and activities
    - RVS and PC optical leak improvement
- Caveats in L1B

TEB Pre-launch Thermal Vacuum Test

- **TEB pre-launch calibrations were performed at**
    - 3 instrument plateau temperatures: 260, 270, and 280K
    - 2 cold focal plane temperatures: 83 and 85K
    - 21 BCS levels: 170 to 340K
- **TEB were calibrated with a quadratic algorithm treating each detector and mirror side independently**
- **Set PV bands (B20-25,27-30) coefficients a0 and a2 to 0 due to SAM resistors change *without* retest**
- RVS measurement not successful on PFM
    - *Note*: At-launch RVS based on the scan mirror witness sample reflectance measurements at NPL and the fixed optics parameters derived from FM1 system level RVS

Thermal Vacuum Configuration for MODIS Pre-launch Calibration

OBC (AOI=26.7˚)

Space View Port (AOI=11.2˚)

Scan Mirror

Cryogenic Space View Source

BCS

SIS 100

SpMA

+45˚ Port
(AOI=60.5˚)

0˚ Nadir Port
(AOI=38˚)

-45˚ Port
(AOI=15.5˚)
(The only angle calibration performed)
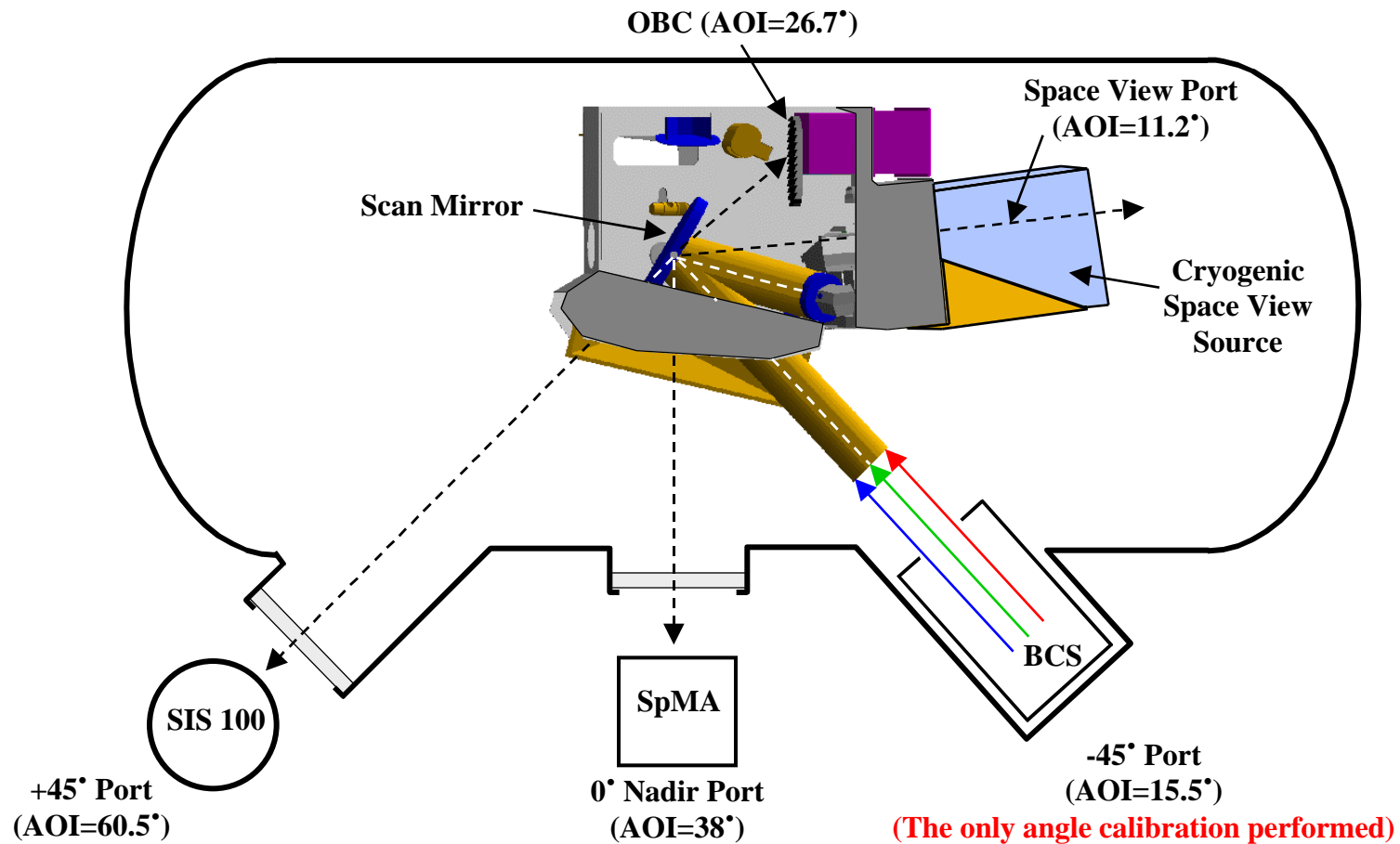
TEB Calibration Algorithm Derivation

When viewing the BCS

$$\varepsilon_{SM}\, L_{SM}$$
$$RVS^{SM}_{BCS}\;\varepsilon_{BCS}\, L_{BCS}$$

15.5°

$$\varepsilon_{SM} = 1 - RVS^{SM}_{BCS}$$

$$\varepsilon_{BCS}\, L_{BCS}$$

BCS

Scan Mirror (SM)

When viewing the Space View Source (SVS)

Cold Source (SVS)

11.2°

$$\varepsilon_{SM} = 1 - RVS^{SM}_{SVS}$$

$$\varepsilon_{SM}\, L_{SM}$$
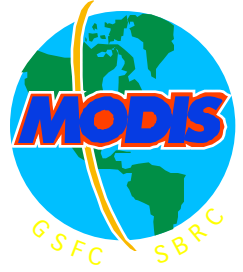
Scan Mirror (SM)
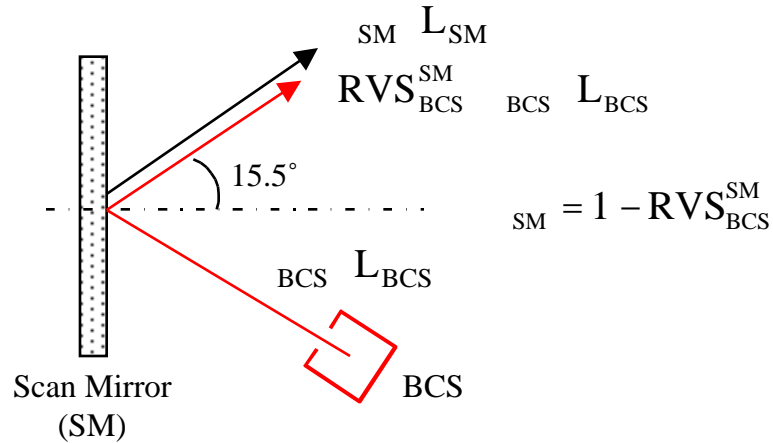
$$L_{BCS\_PATH} = RVS^{SM}_{BCS}\;\varepsilon_{BCS}\, L_{BCS} + \varepsilon_{SM}\, L_{SM} + L_{BKG}$$

- BCS Source Reflected
- Scan Mirror Emission At BCS Angle
- Instrument Background
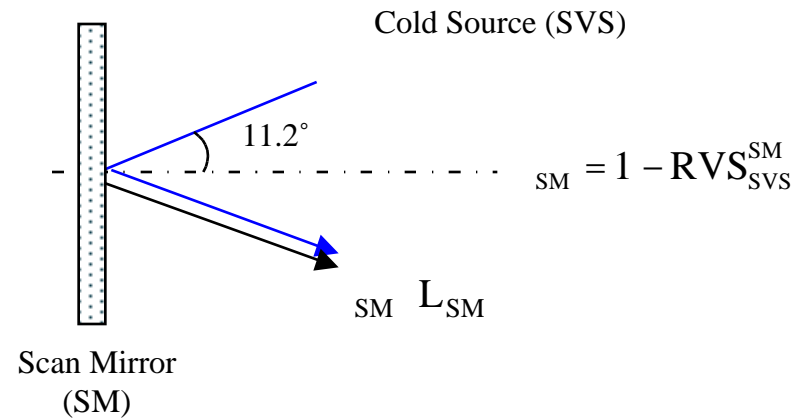
$$L_{SVS\_PATH} = \varepsilon_{SM}\, L_{SM} + L_{BKG}$$

- Scan Mirror Emission At SV Port Angle
- Instrument Background

Equate the difference signal to a Quadratic Fitting Function to determine pre-launch a_0 and a_2:

$$RVS^{SM}_{BCS}\;\varepsilon_{BCS}\, L_{BCS} + \left(RVS^{SM}_{SVS} - RVS^{SM}_{BCS}\right) L_{SM} = a_0^{BCS} + a_1^{BCS} dn_{BCS} + a_2^{BCS} dn_{BCS}^2 \qquad (1)$$

When Viewing the On-Board Blackbody (OBC)

$$L_{OBC\_PATH} = RVS_{OBC}^{SM} \; \varepsilon_{OBC} \; L_{OBC} + RVS_{OBC}^{SM} \; (1 - \varepsilon_{OBC}) \; \varepsilon_{CAV} \; L_{CAV} + \varepsilon_{SM} \; L_{SM}$$

OBC Source Reflected

$+L_{BKG}$

Scan Cavity Contribution

Scan Mirror Emission At OBC Angle

Instrument Background

$\varepsilon_{SM} = 1 - RVS_{OBC}^{SM}$

$\varepsilon_{CAV} \cdot L_{CAV}$

$(1 - \varepsilon_{OBC}) \cdot \varepsilon_{CAV} \cdot L_{CAV}$

$\varepsilon_{OBC} \cdot L_{OBC}$

Scan Mirror (SM)

$RVS_{OBC}^{SM} \; (1 - \varepsilon_{OBC}) \; \varepsilon_{CAV} \; L_{CAV}$

$RVS_{OBC}^{SM} \; \varepsilon_{OBC} \; L_{OBC}$
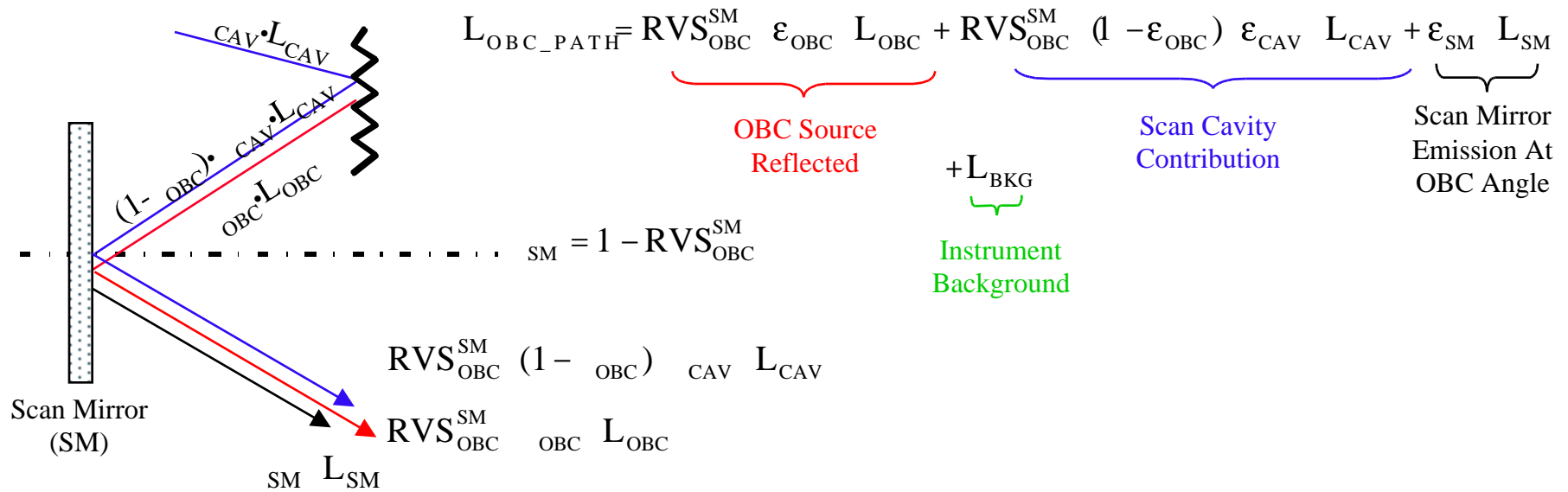
$\varepsilon_{SM} \; L_{SM}$

Subtracting the Space View Path and solve for the on-board linear gain term b_1:

$$RVS_{OBC}^{SM} \; \varepsilon_{OBC} \; L_{OBC} + \left(RVS_{SVS}^{SM} - RVS_{OBC}^{SM}\right) \; L_{SM} + RVS_{OBC}^{SM} \; (1 - \varepsilon_{OBC}) \; \varepsilon_{cav} \; L_{cav}$$

$$= a_0^{BCS} + b_1^{OBC} dn_{OBC} + a_2^{BCS} \; dn_{OBC}^2$$

(2)

The system level measured Response versus Scan Angle, RVS( ), is normalized to unity at the scan angle of the OBC BB: $RVS_{OBC}^{SM} = 1$

The linear gain term is continuously determined via the OBC Blackbody scan by scan:

$$b_1^{OBC} = \frac{\epsilon_{OBC} L_{OBC} + (RVS_{SVS} - 1) L_{SM} + (1 - \epsilon_{OBC}) \epsilon_{cav} L_{cav} - a_0^{BCS} - a_2^{BCS} dn_{OBC}^2}{dn_{OBC}} \qquad (3)$$

Where

$$dn_{OBC} = DN_{OBC} - DN_{SVS}$$

The Earth view radiance is given by:

$$\bar{L}_{EV}( ) = \frac{1}{RVS_{EV}( )} \left\{ \left(a_0^{BCS}(T_{inst}) + b_1^{OBC} dn_{EV( )} + a_2^{BCS}(T_{inst}) dn_{EV( )}^2 \right) - (RVS_{SVS} - RVS_{EV}( )) \bar{L}_{SM} \right\} \quad (4)$$

- Wavelength dependent parameters are weighted by the Relative Spectral Response RSR( )
- $a_0(T_{inst})$ and $a_2(T_{inst})$ are functions of the instrument temperature

MODIS Operational and Calibration Ranges
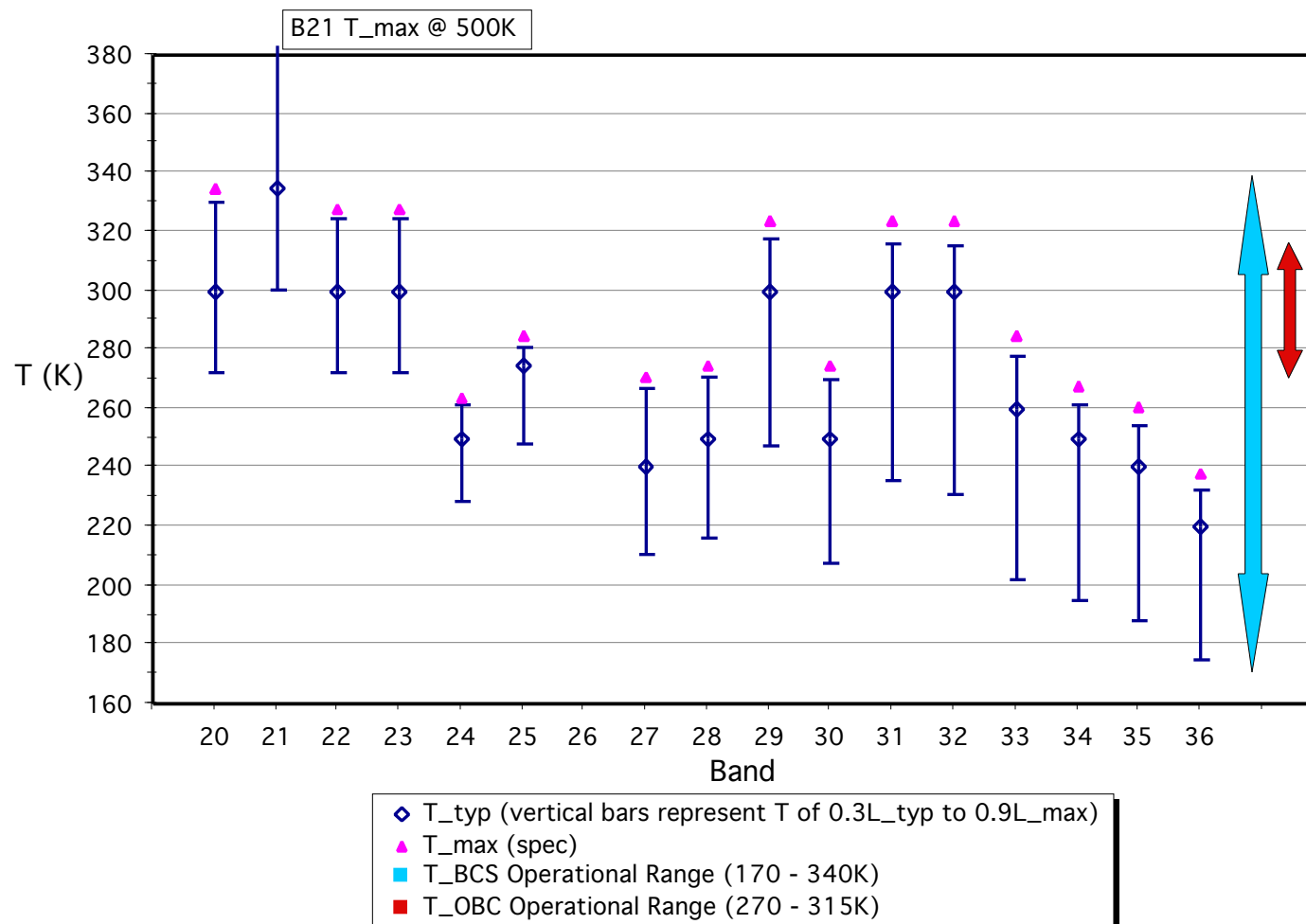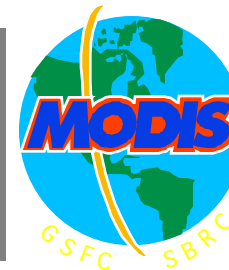
PFM Pre-launch OBC Blackbody Effective Emissivity from RC02 & MFI09 Tests
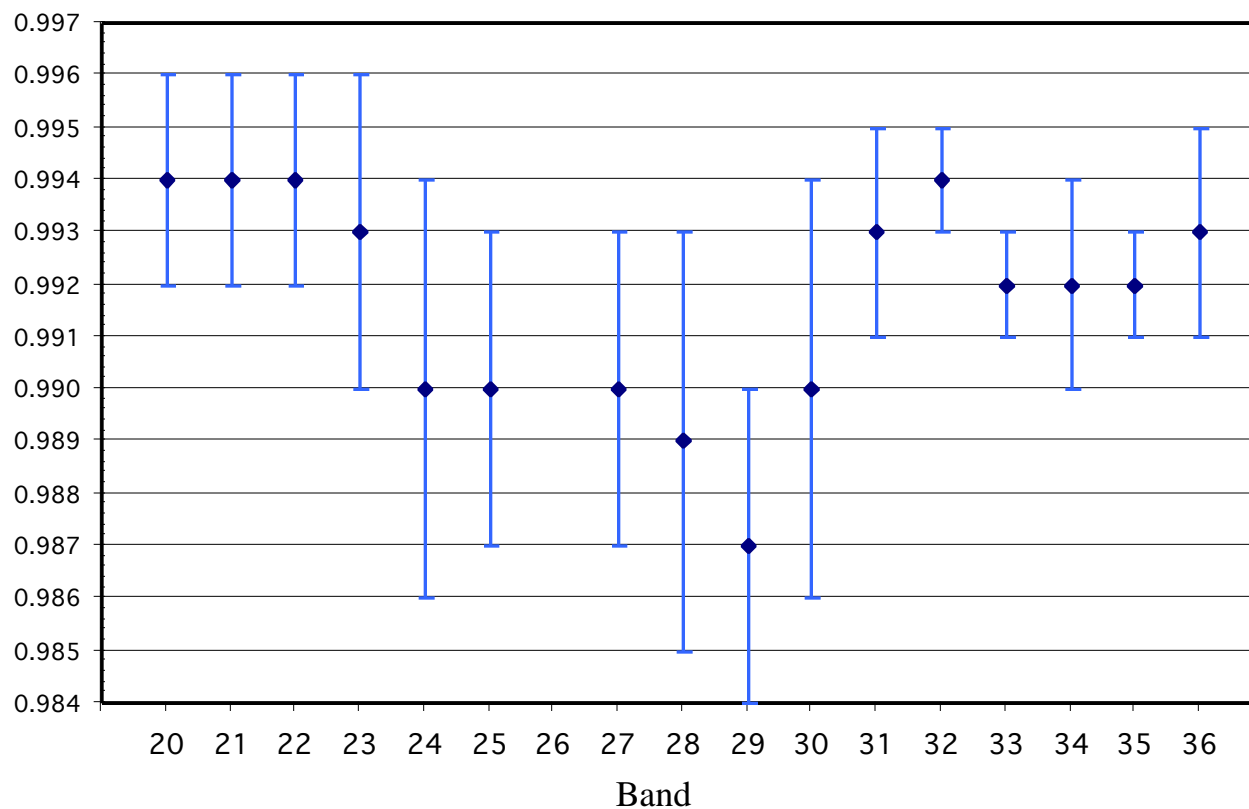
Band	OBC	OBC
B20	0.9938	0.0016
B22	0.9936	0.0015
B23	0.9932	0.0029
B24	0.9897	0.0035
B25	0.9902	0.0030
B27	0.9903	0.0029
B28	0.9891	0.0035
B29	0.9865	0.0025
B30	0.9903	0.0035
B31	0.9931	0.0017
B32	0.9935	0.0014
B33	0.9919	0.0014
B34	0.9922	0.0015
B35	0.9923	0.0014
B36	0.9927	0.0017

Principal Scan Angles Mapped to Scan Mirror Angles of Incidence
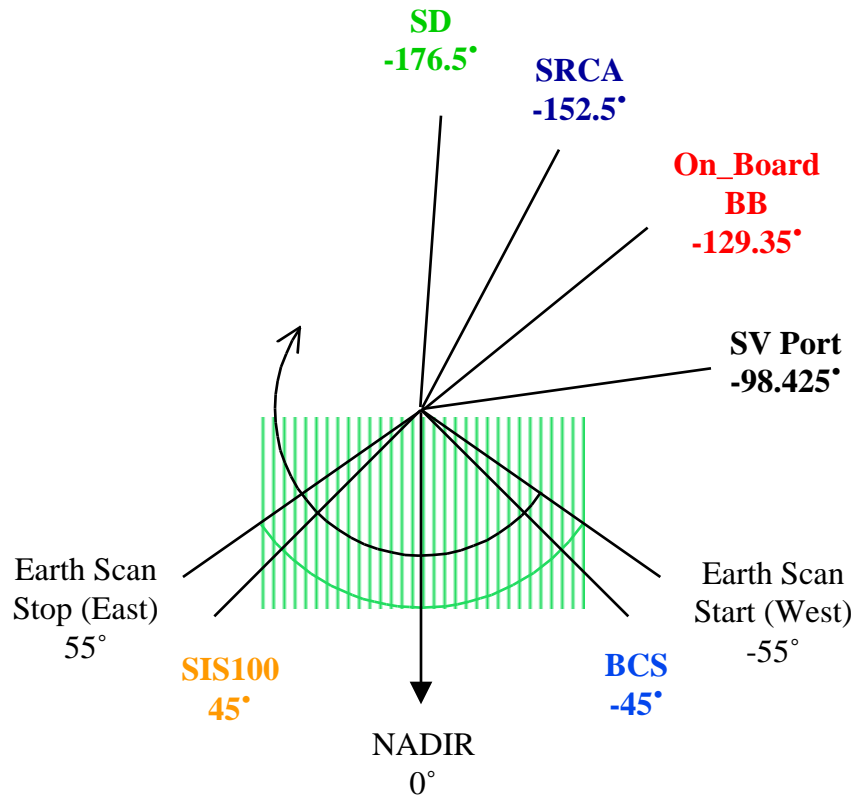
Principal Scan Angles
(Earth View: -55° to 55°)
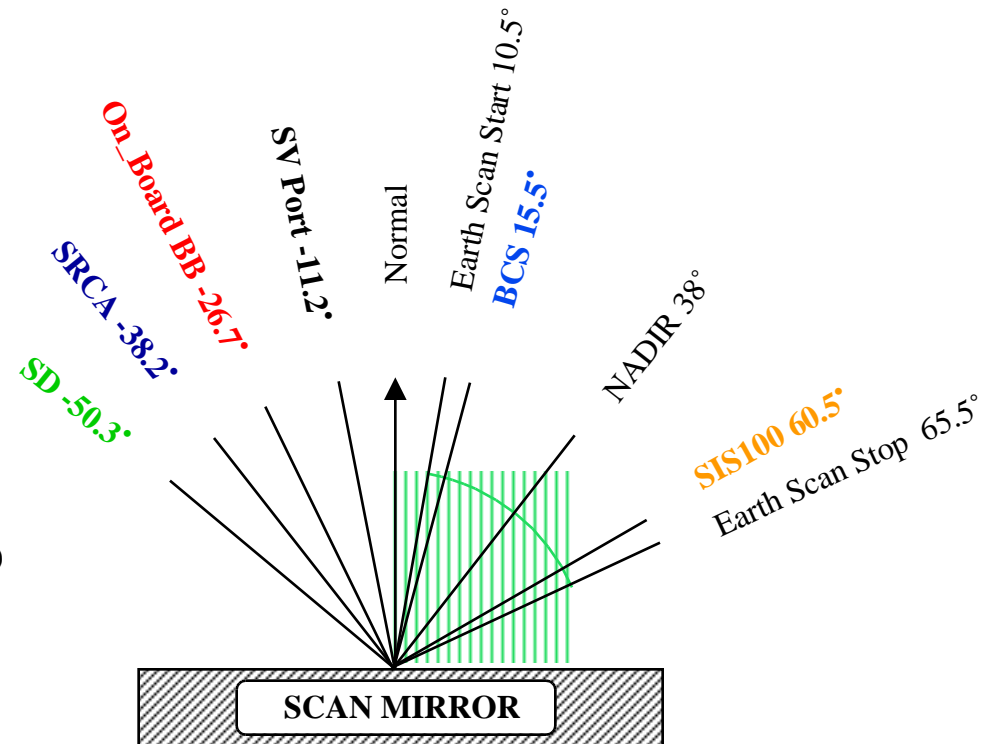
Angles of Incidence
(Earth View: 10.5° to 65.5°)

Scan Mirror Average Reflectance
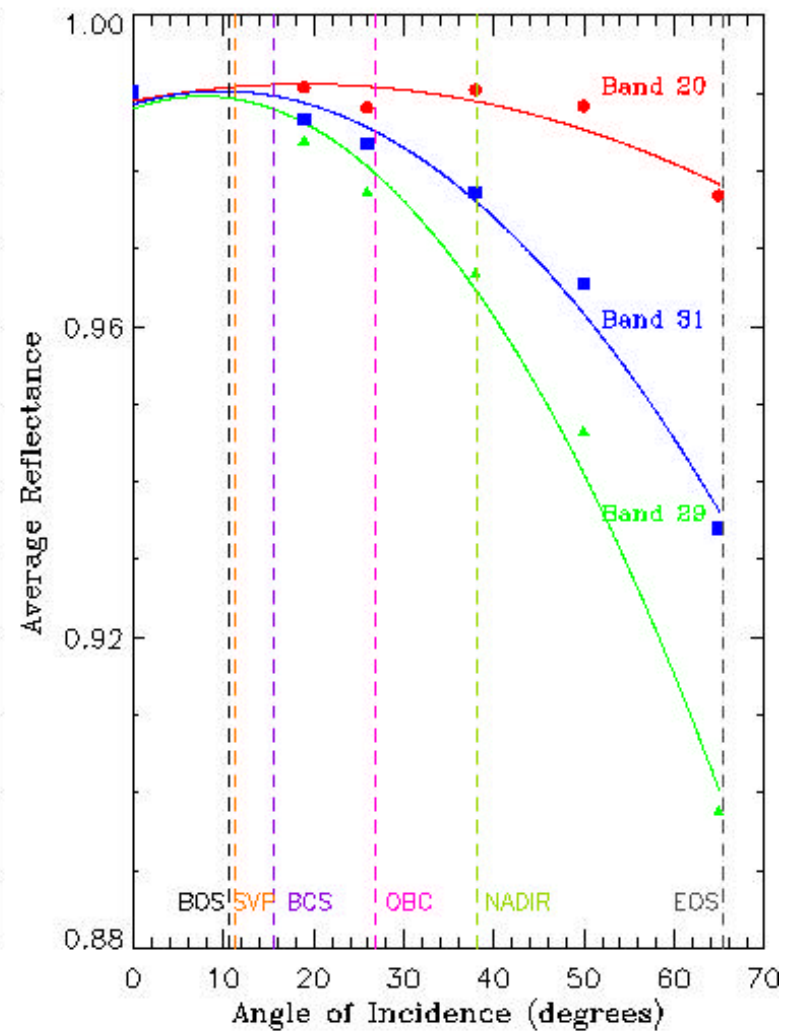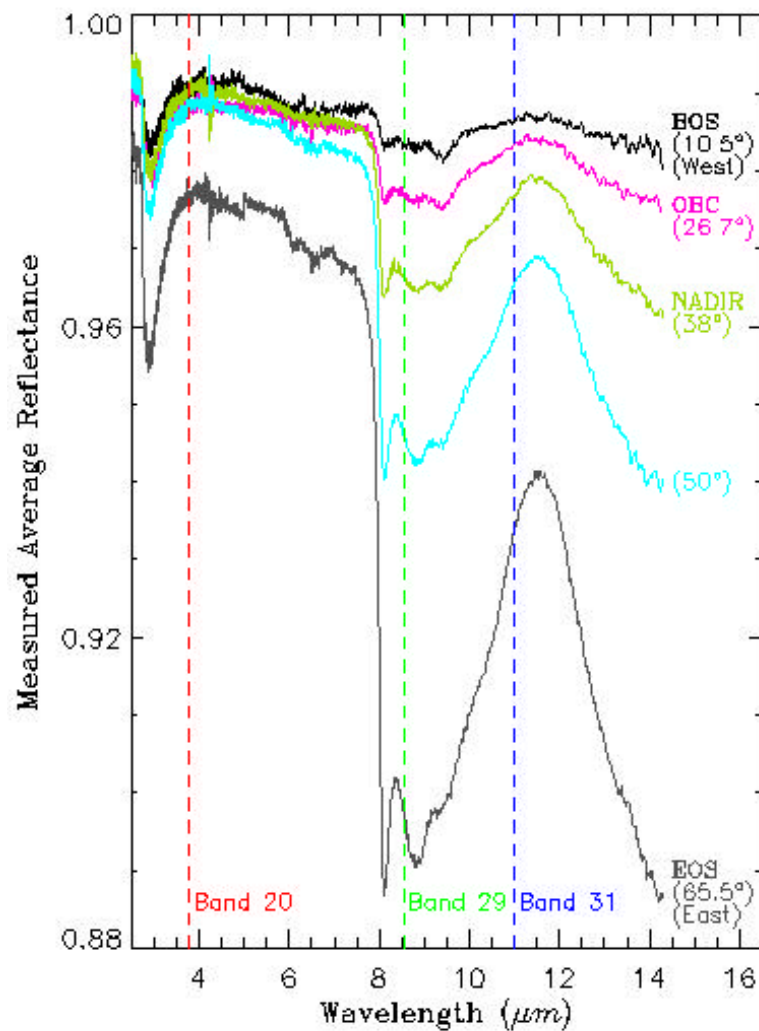
Pre-launch RVS Determination

- **No valid system level RVS measurements for PFM TEB**

- **Witness sample reflectance measurements (by NPL) and fixed optics parameters (C_{Fix}) derived from the Flight Model (FM1) system level measurements RVS are used to derive the PFM RVS**

$$RVS \quad \frac{\rho_S + \rho_P}{2} + C_{Fix} \quad \frac{\rho_S - \rho_P}{2}$$

- **At launch, same RVS applied to both mirror sides and all detectors within the same band**

TEB Pre-launch RVS

Terra MODIS Pre-launch Response Versus Scan Angle (RVS)
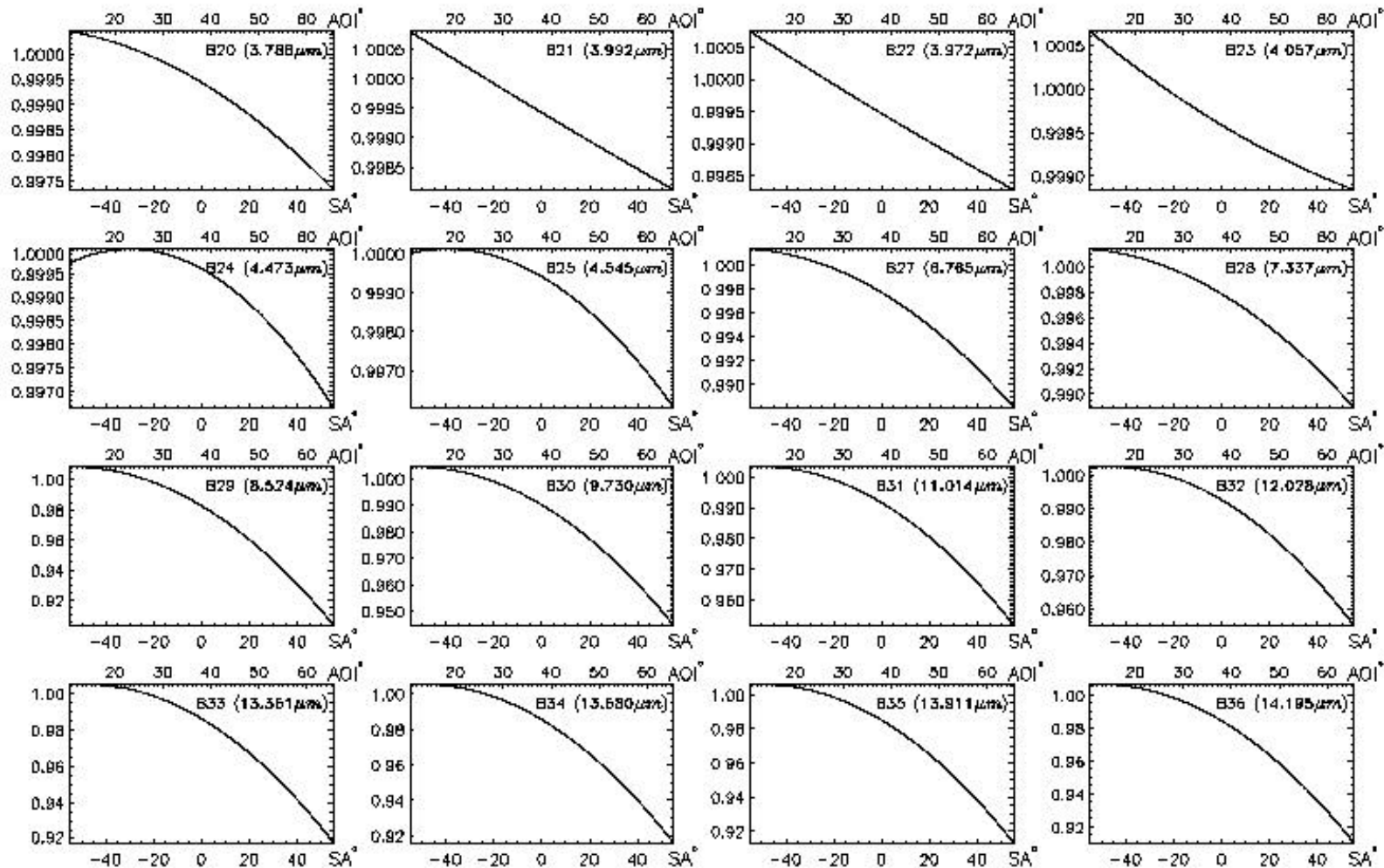
On-orbit Calibration Algorithm

Using OBC BB warm-up/cool-down cycle to a Quadratic Fitting Function:

$$\epsilon_{OBC}\, L_{OBC} + \left(RVS_{SVS} - 1\right) L_{SM} + \left(1 - \epsilon_{OBC}\right)\epsilon_{cav}\, L_{cav} = b_0^{OBC} + b_1^{OBC} dn_{OBC} + b_2^{OBC}\, dn_{OBC}^2 \qquad (5)$$

Thus the scan-to-scan on-board linear gain b_1 becomes:

$$b_1^{OBC} = \frac{\epsilon_{OBC}\, L_{OBC} + \left(RVS_{SVS} - 1\right) L_{SM} + \left(1 - \epsilon_{OBC}\right)\epsilon_{cav}\, L_{cav} - b_0^{OBC} - b_2^{OBC}\, dn_{OBC}^2}{dn_{OBC}} \qquad (6)$$

The Earth View Radiance Retrieval Equation:

$$\bar{L}_{EV()} = \frac{1}{RVS_{EV()}}\left\{\left(b_0^{OBC}(T_{inst}) + b_1^{OBC} dn_{EV}(\ ) + b_2^{OBC}(T_{inst})\, dn_{EV}^2(\ )\right) - \left(RVS_{SV} - RVS_{EV}(\ )\right)\bar{L}_{SM}\right\} \qquad (7)$$

TEB On-orbit Calibration and Activities

- **On board linear gain b1 retrieved from OBC BB scan by scan**
  - *Note*: 40-scan average algorithm used in L1B
- **On-orbit analysis using OBC BB warm-up and cool-down cycle ranging temperature from 270 to 315K and retrieve b0 and b2 to replace at-launch values of a0 and a2**
  - *Note*: Perform radiometric calibration once a month and update b0 and b2 if determined to be effective
- **Relative RVS based on closed Nadir Aperture Door data set (Day 118) to eliminate mirror side differences for each detector**
  - *Note*: Match mirror side 2 retrieved radiance to mirror side 1

TEB On-orbit Calibration and Activities
(continued)

- **PC bands (B32-36) optical leak correction improvement**
  - Using Moon's observation data set by detectors
- **Itwk/Vdet configuration testing for Electronic-Xtalk**
  - Using Moon's observation, OBC BB warm-up cycle, and SRCA data sets
  - Change from 110/226 to 79/110 on Day 305

Band31 (11 µm) L vs dn Quadratic Fitting Using OBC BB Warm-up Activity

PFM Band 31 Calibration Quadratic Fitting from On-Orbit OBC BB Warm-up
(2000305.2300-306.0235; B-side; Itwk/Vdet:79/110; Mirror side 1)
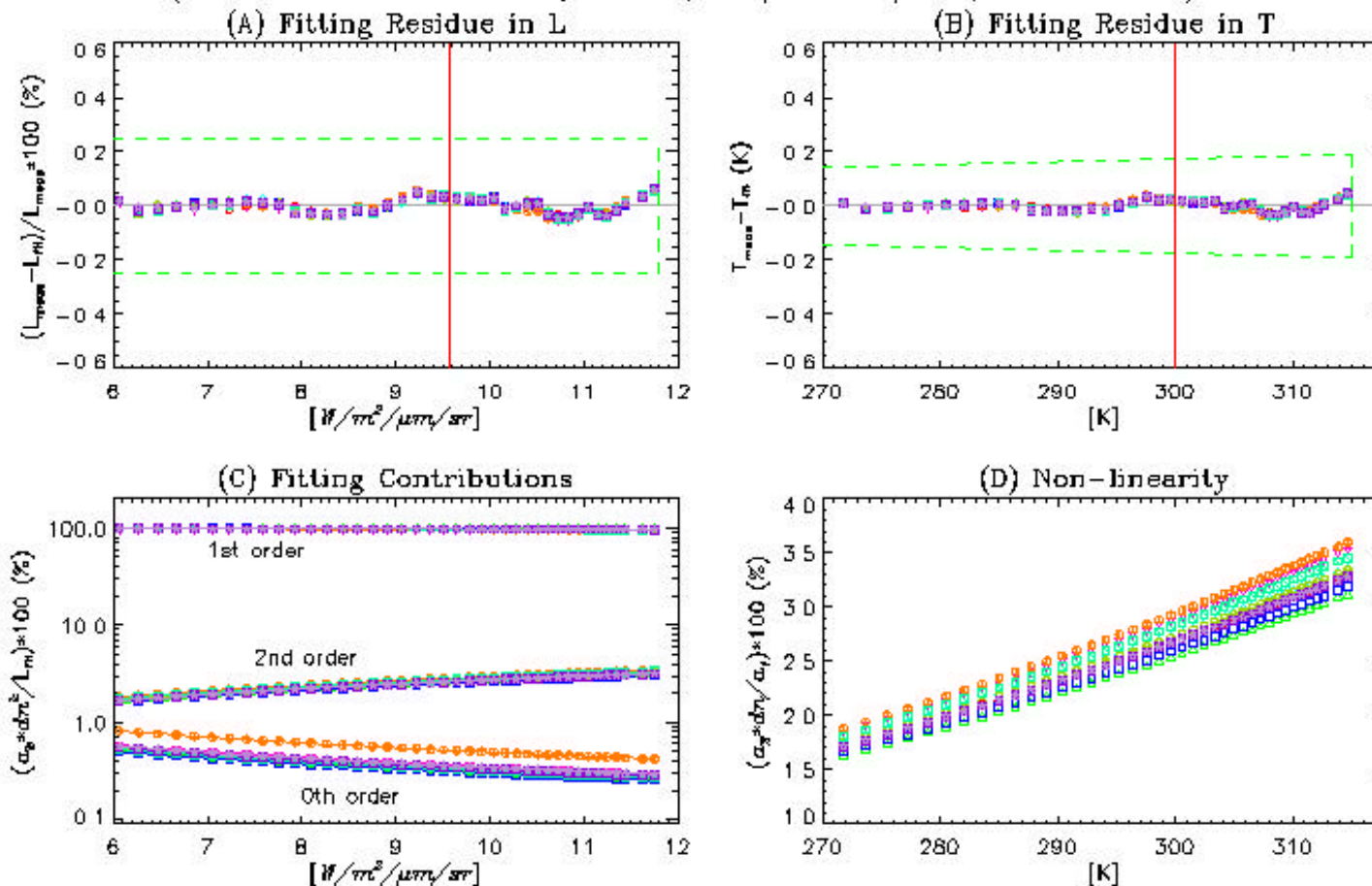
RVS Problem (Band 35, 13.9 μm)
South Pacific Ocean; March 13, 2000 at 07:30 UTC

Terra MODIS 2000073.0730
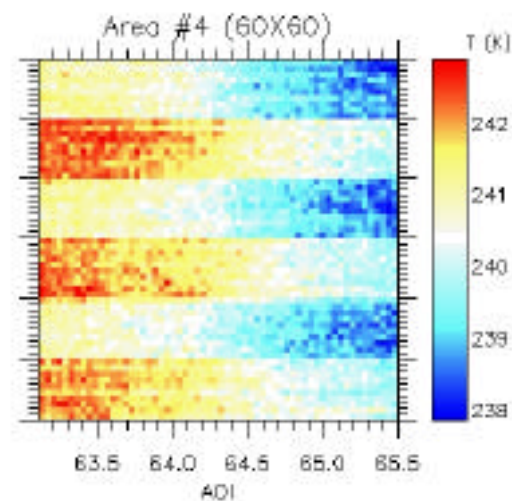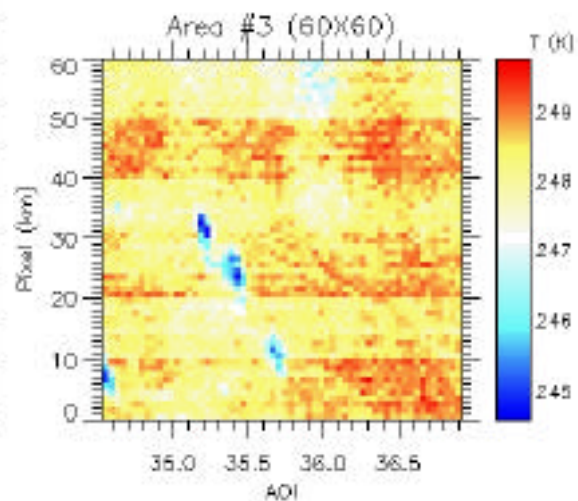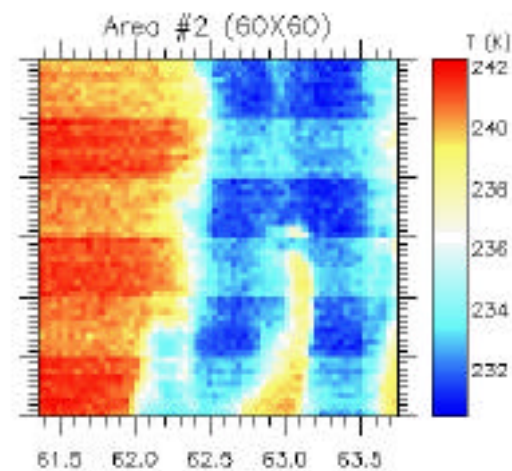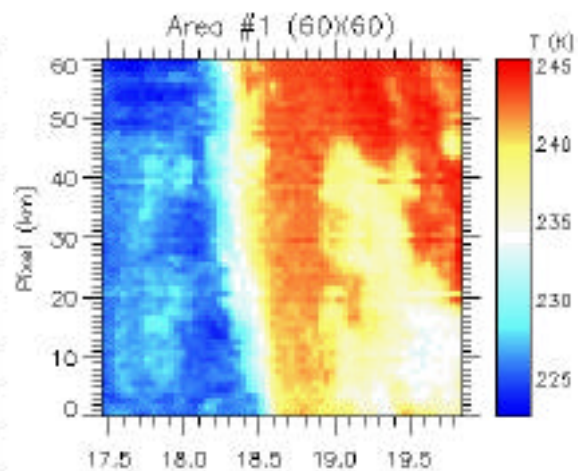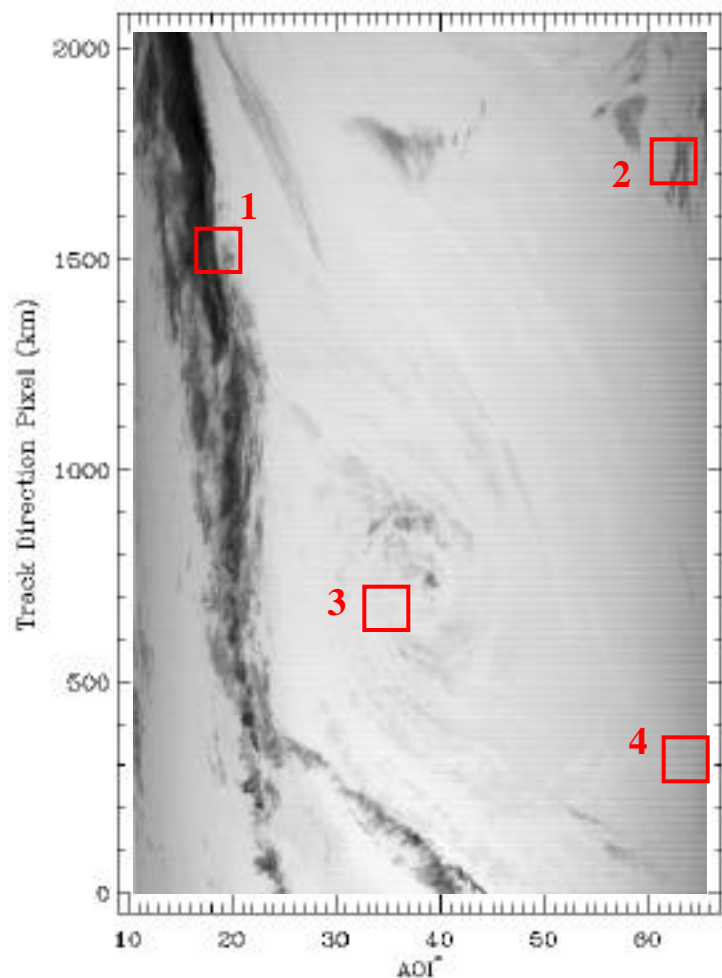
Temperature Retrieval Using Pre-launch RVS

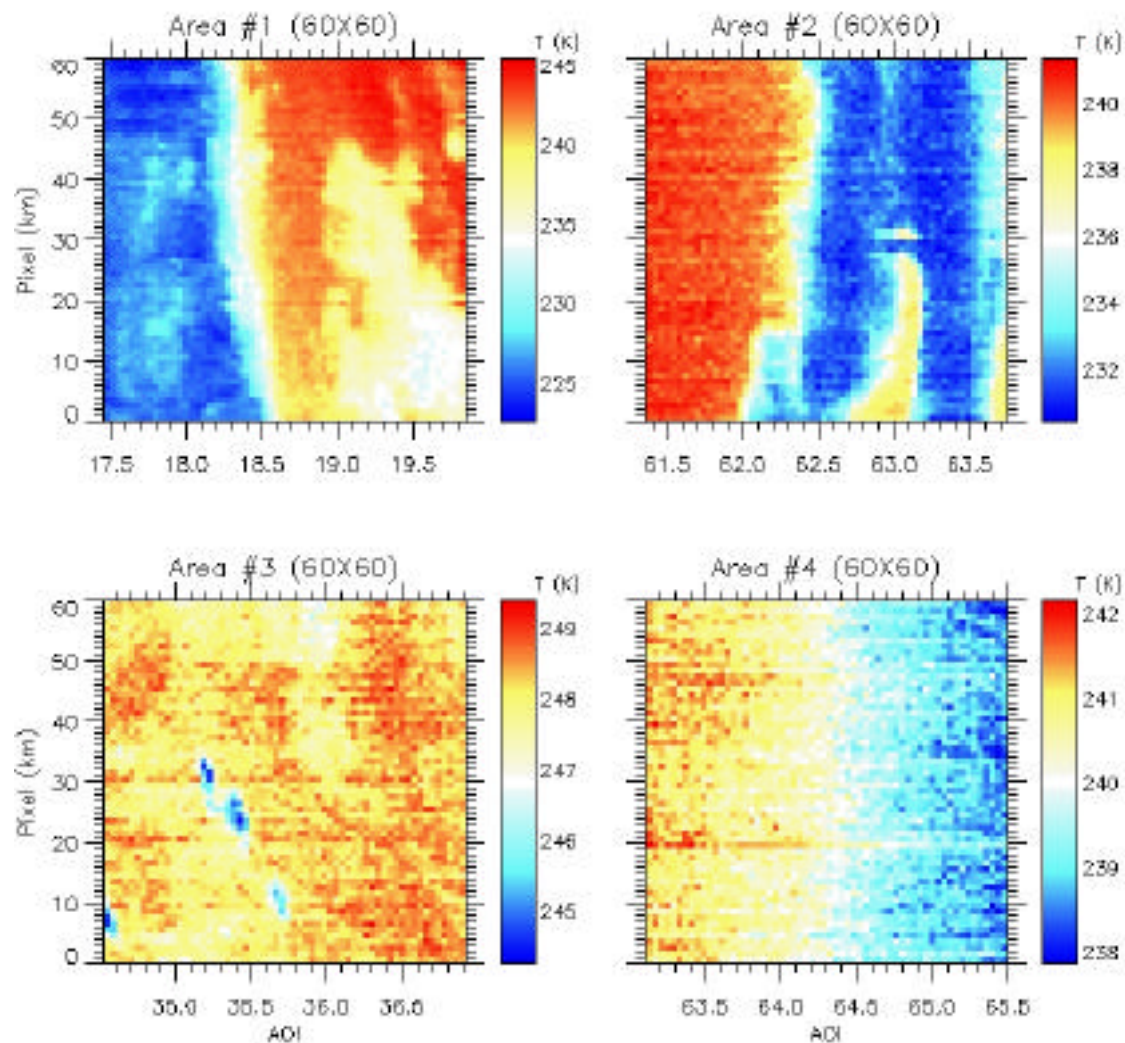# On-orbit Closed NAD RVS Results for B33-36 (Channel Dependent)
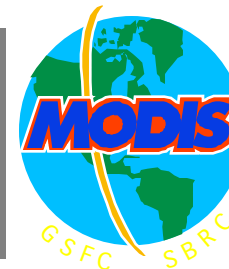
Data Granule: 2000118.0355
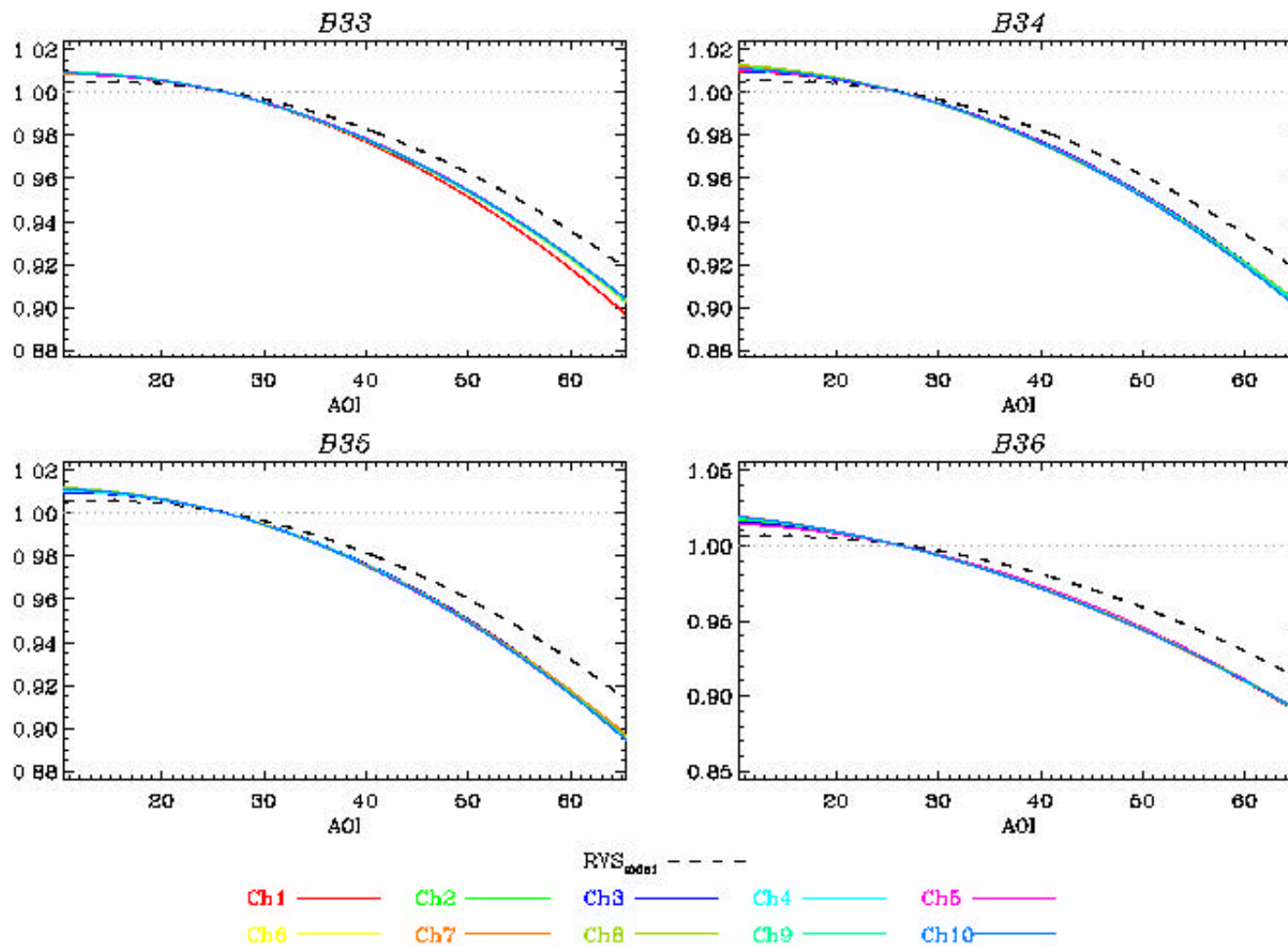
RVS Improvement (Band 35, 13.9 µm)
South Pacific Ocean; March 13, 2000 at 07:30 UTC
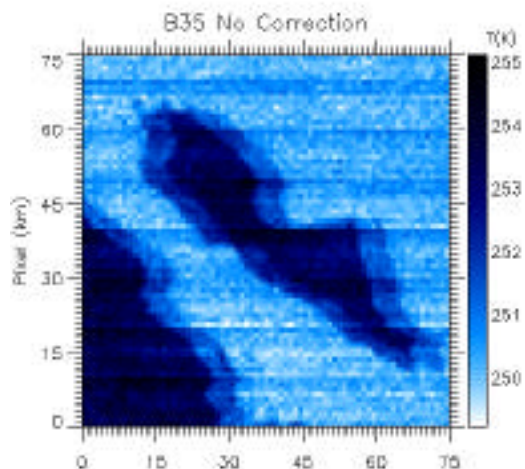

Temperature Retrieval Using New On-orbit RVS

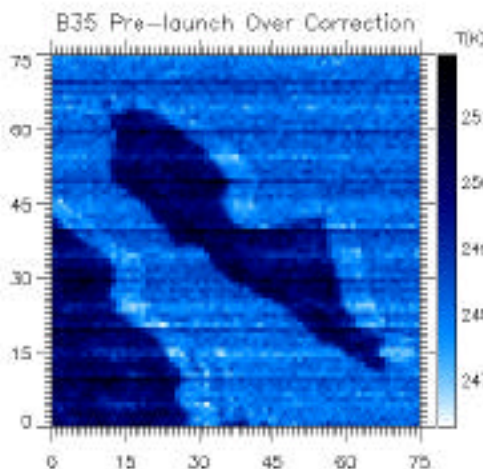# PC Optical Leak Correction Improvement
Top: B35, Bottom: B36
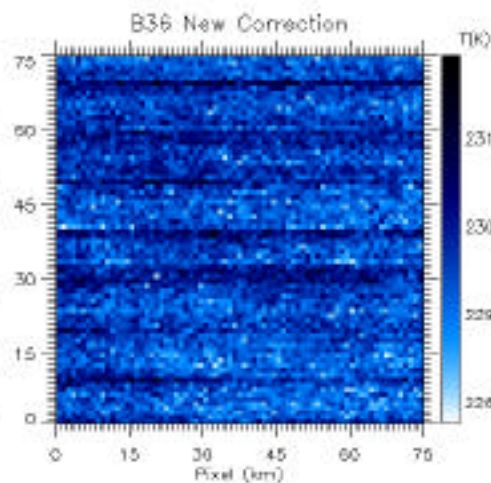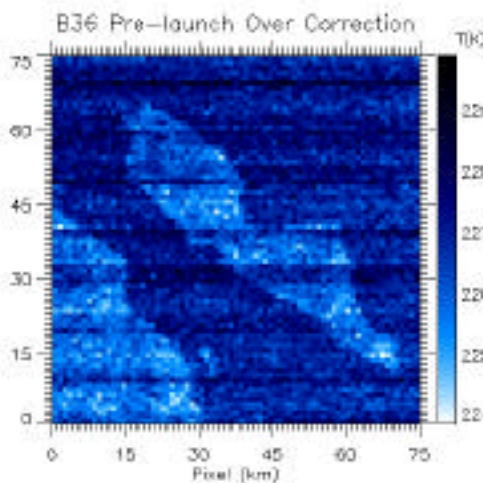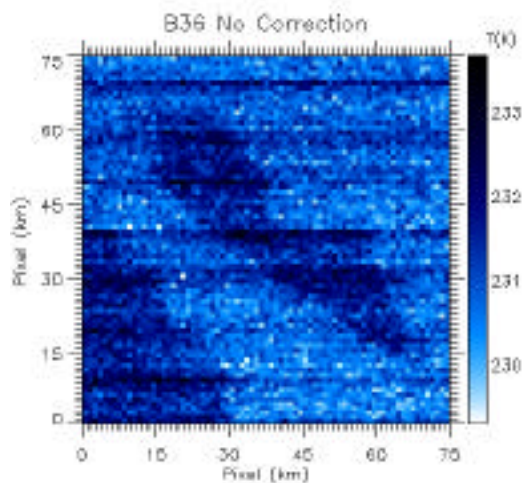### Baja California; March 18, 2000, 18:35 (2000078.1835)
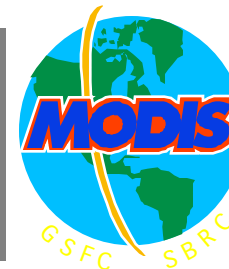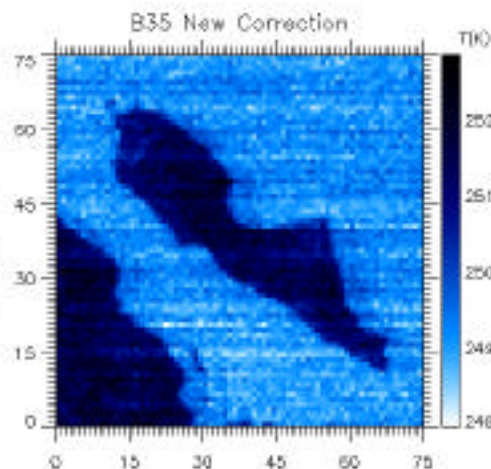
No correction

Using Pre-launch correction coefficients

Using new on-orbit correction coefficients

Caveats in Current TEB L1B

- **Optical leak from B31 into B32 through B36**
  - Improved leak correction coefficients from Moon's observations
  - B36 coefficient may need fine tuning
- **Electronic cross-talk in SWIR/MWIR focal plane**
  - Significant reduction of cross-talk after switching to Itwk/Vdet=79/110
  - Further analysis and testing are being developed
- **Band 27 anomalous bandwidth change that causes inaccurate center wavelength and radiance retrieval**
  - Due to the temperature change of the intermediate stage cooler window which has the dielectric coating
  - A revised algorithm including bandwidth effect is being developed

Caveats in Current TEB L1B
(continued)

- **Incomplete knowledge of sensor RVS**
  - Deep space maneuver needed for instrument true RVS measurement
- **Mirror rotation correlated noise**
  - Change from calibration configuration Day 174,…, 306
  - Seems correlated with formatter resets, absent (same as calibration configuration) on B-side
- **Pre-launch calibration performed *ONLY* at one AOI (=15.5°)**